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MONAZITE SAND

BY

LAWRENCE G. HOUK

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

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By Lawrence G. Houk[2/]

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INTRODUCTION

Monazite sand is the only commercial source of cerium, other rare-earth metals and thorium. Although used in rather small quantities, it is essential to many industries. The United States is entirely dependent upon British India and Brazil for its supplies. Monazite sand or sand imported under the tariff classification for monazite was shipped to the United States in greater quantities in 1940 than ever before. About 75 percent of our imports was from British India and most of the remainder from Brazil. If need be, Brazilian production can be expanded to supply all of our essential requirements, and as the theater of war expands in the Pacific Brazil may supersede India as the principal source.

PHYSICAL PROPERTIES

The mineral monazite is generally honey yellow or may vary from greenish yellow to clove brown. The grains are small and resinous in luster, and range from subtranslucent to opaque. The specific gravity varies

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from 4.9 to 5.3, and the hardness from 5.0 to 5.5. The mineral is brittle, uneven in its fracture, and magnetic enough to be concentrated electromagnetically in a strong field. Owing to its content of mesothorium and sometimes radium it is radioactive.

CHEMICAL COMPOSITION

Monazite sand is the commercial treasure house of rare-earth metals and thorium. It generally contains all of the rare-earth elements in some degree. Monazite is essentially a monoclinic phosphate of rare earths with thorium present, probably as the silicate. The formula is generally written (Ce, La, Di) PO_4, or (Ce La Di)$_2O_3P_2O_5$, and does not indicate the thoria content, which ranges from less than 1 to 18 percent[3], nor the minor constituents, such as samarium, erbium, and ytterbium. The chemical composition of monazites from various parts of the world[4], shown in tables 1, 2, 3, and 4, are noteworthy because of their variable content of ceria, other rare-earth oxides, and thoria.

3/ Pratt, J. H., Monazite and Monazite Mining in Carolinas: Am. Inst. Min. and Met. Eng., 1908, p. 1

4/ Schaller, Waldemar T., Thorium, Zirconium, and Rare-Earth Minerals in 1919: U. S. Geol. Survey, Mineral Resources of the United States, pt. II, 1919, pp. 12-13.

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TABLE 1. - Analyses of samples of monazite from the United States

	1	2	3	4	5	6	7
ThO_2	6.43	1.48	1.22	1.43	2.32	1.19	7.00
Ce_2O_3	31.38	37.26)	54.03	(32.93)	a65.32	c61.77	(34.50
$(La,Di,Yt)_2O_3$	30.88	31.60)	-	(b25.54)	-	-	(28.80
P_2O_5	29.28	29.32	23.43	18.38	28.16	26.05	23.00
SiO_2	1.40	.32	1.60	6.40	3.20	1.45	2.00
ZrO_2	-	-	3.25	-	-	-	.70
TiO_2	-	-	-	4.67	.61	1.40	.90
Fe_2O_3	-	-	5.58	7.83	-	.65	-
Al_2O_3	-	-	2.49	1.62	-	.15	-
CaO	-	-	-	1.20	-	-	.70
H_2O	.20	.17	-	-	-	-	-
Miscellaneous	-	-	c7.74	-	-	d6.39	-
	99.63	100.15	99.34	100.00	99.61	99.05	100.60

a Including ZrO_2 and BeO.
b Including ZrO_2, BeO, and Ta_2O_5.
c Including 4.12 percent $(Cb, Ta)_2O_5$ and 3.62 percent FeO.
d Ta_2O_5.

1. Sand from Brindletown district, Burke County, N. C. Penfield, S. L., Am. Jour. Sci., 3d ser., vol. 24, p. 252, 1882.
2. Alexander County, N. C., 3 miles east of the hiddenite mine. Penfield, S.L., and Sperry, E. S., Am. Jour. Sci., 3d ser., vol. 36, pp. 317-331, 1888.
3. "Carolina." (Probably Belwood, N. C.) Monazite separated from sand containing 78.39 percent monazite. Tschernik, G. P., Acad. Imp. Sci. St. Petersburg Bull., vol. 2, pp. 243-254, 1908.
4. Monazite sand from Burke, N. C. Not pure monazite. Glaser, C. Estimation of thoria; chemical analysis of monazite sand: Am. Chem. Soc. Jour., vol. 18, pp. 782-793, 1896.
5. Nearly pure monazite, from Shelby, N. C. Idem.
6. Nearly pure monazite, from Belwood, N. C. Idem.
7. From South Carolina. Tschernik, G. P., op. cit.

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TABLE 2. - Analyses of samples of monazite from Brazil

	1	2	3	4	5	6
ThO_2	9.23	10.05	1.09	6.06	6.50	6.49
Ce_2O_3	31.21	32.14	32.46	) 62.92	62.10	(31.28
$(La, Di)_2O_3$	-	25.99	36.02	)		(30.88
P_2O_5	28.36	25.51	29.18	28.50	28.46	29.28
SiO_2	10.14	2.63	-	.75	.64	1.40
ZrO_2	5.74	.60	-	-	-	-
TiO_2	2.62	-	-	-	-	-
Fe_2O_3	4.22	1.79	.61	.97	1.50	-
Al_2O_3	.32	.84	-	.10	.08	-
CaO	1.11	.20	.10	.21	.30	-
H_2O	-	.92	-	.38	.64	.20
Ta_2O_5	1.16	-	-	-	-	-
	94.11	100.67	99.46	99.89	100.22	99.53

1. Monazite from river bed, in large pieces weighing as much as 2 pounds; derived from pegmatite Southern Serra dos Aymores, Espirito Santo. Freise, F., Zeitschr. prakt. Geologie, vol. 18, pp. 123-124, 1910.
2. From river sands of Rio Paraguassir in Bahia, Bandeiro do Mello. Hussak, E., and Reitinger, J., Zeitschr. Kryst. Min., vol. 37, pp. 550-579, 1903.
3. Sand from Bandeirinha, near Diamantina, Mines Geraes. Idem.
4. Espirito Santo. Johnstone, S. J., Soc. Chem. Industry Jour., vol. 33, pp. 55-59, 1914.
5. Alcobaca, Borhia. Idem.
6. Brazilian monazite. Analysis furnished by F. H. Lee. Gottschalk, A. L. M., Min. and Eng. World, May 15, 1915.

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TABLE 3. - Analyses of samples of monazite from the Malay Peninsula and Australia

	1	2	3	4	5	6
ThO_2	8.38	3.40	3.53	9.41	5.03	3.80
Ce_2C_3	25.46	33.74	66.45	62.82	(33.06	31.10
$(La, Di)_2O_3$	35.52	33.44			(30.35	34.30
P_2O_5	23.92	26.58	27.87	23.71	23.70	26.89
SiO_2	.92	1.45	1.08	2.20	1.22	1.96
Fe_2O_3	2.78	.65	.34)	1.13	(2.21	.42
Al_2O_3	.84	.03	.07)		(.44	.64
CaO	.61	.33	.17	.29	a1.11	.34
H_2O	1.28	.94	.52	94	.59	.58
	99.71	100.56	100.33	100.50	100.71	100.03

aCaO, 0.90; MgO, 0.21.

1. Concentrated monazite from the Sempang Tin Co., Pahang. Occurrence of monazite in the tin-bearing alluvium of the Malay Peninsula; Imp. Inst. Bull., vol. 4, pp. 301-309, 1906.
2. Isolated from concentrate, Puchong, Babi, River Kenring, Perak, Johnstone, S. J. Monazites from some new localities: Jour. Chem. Industry, vol. 33, pp. 55-59, 1914.
3. Isolated from concentrate, Kulim, Kedah. Idem.
4. Kelantan. Idem.
5. Forty pebbles from Moolyella, Western Australia. Simpson, E. S., The occurrence of monazite at Cooglegong and Moolyella: Western Australia Geol. Survey Bull. 48, 1913.
6. Single crystal from Cooglegong, Western Australia. Idem.

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TABLE 4. - Analyses of samples of monazite from India and Ceylon.

	1	2	3	4	5	6
ThO_2	10.22	8.65	10.75	10.29	9.49	7.90
Ce_2O_3	31.90)	61.73	(26.71	27.37	27.15)	56.50
$(La, Di)_2O_3$	28.46)		(31.52	32.27	33.52)	
P_2O_5	26.82	26.50	24.61	27.67	26.12	26.80
SiO_2	.90	1.00	2.47	1.03	1.67	1.92
Fe_2O_3	1.50	1.09	1.09	.81	.87	1.40
Al_2O_3	.17	.12	.70	.17	.17	.13
CaO	.20	.13	.85	.41	.45	.27
H_2O	.46	.45	.93	.20	.48	2.20
U_3O_8	-	-	-	-	-	2.66
	100.63	99.67	99.63	100.22	99.92	99.78

a Johnstone, S. J., Monazites from some new localities: Jour. Chem. Industry, vol. 33, pp. 55-59, 1914.

1. Sand from Travancore, India.
2. Isolated from a concentrate from Travancore, India.
3. From sand from Niriellaganga, Ceylon.
4. Monazite pebble from Ratnapura, Ceylon.
5. Monazite pebble from Muladiwanella Durayakanda, Gilimale, Ceylon.
6. Washed from pegmatite containing 100 grams monazite per metric ton (0.01 percent) from Rifle Range Stream, Moon Plains, Ceylon: Imp. Inst. Bull. vol. 14, p. 349, 1916.

The rare-earth elements are a group of metallic elements similar in chemical properties and regarded as occupying the position of a single element in group 3 of the periodic table. Their chemical affinity may be attributed to their similar exterior electronic pattern and the physical differences to the interior electronic pattern. Rare-earth elements are listed below, together with their atomic weights and numbers.

Atomic No.	Chemical Symbol	Element	Atomic Weight
57	La.	Lanthanum	138.92
58	Ce	Cerium	140.13
59	Pr	Praseodymium	140.92
60	Nd	Neodymium	144.27
61	Il	Illinium	?
62	Sm	Samarium	150.43
63	Eu	Europium	152.0
64	Gd	Gadolinium	157.3
65	Tb	Terbium	159.2
66	Dy	Dysprosium	162.46
67	Ho	Holmium	163.5
68	Er	Erbium	167.2
69	Tm	Thulium	169.4
70	Yb	Ytterbium	173.04
71	Lu	Lutecium	175.0

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IDENTIFICATION

Monazite sand grains can easily be cracked between the teeth, and this simple field test is at least indicative. Other confirmatory tests include that for radioactivity with photographic plate or electroscope, specific-gravity determination, and the test for phosphorus. Although no single test is conclusive, minerals of the proper color and appearance from favorable localities that pass all the foregoing tests are reasonably certain to be monazite.5/

The direct-vision band spectroscope with natural sunlight may be used to detect the presence of rare earths in monazite. Identification is accomplished by spreading the sand upon a piece of paper with natural sunlight falling directly upon it and viewing with a direct-vision spectroscope. When rare-earth oxides are present, two dark absorption bands appear in the spectrum, which is divided into a scale of 63 mm., a fairly broad dark line between red and yellow, and a narrower dark line in the green. The first and broader dark line is visible between 13 and 15 mm. lines and the other between 21 and 22 mm. on the scale. The dark bands are due to the presence of neodymium, praseodymium, and erbium.6/

A short microchemical method of identifying monazite is to warm the sand in concentrated H_2SO_4, decant a few drops, evaporate to small volume, transfer to microscope slide, and add a drop of concentrated sodium acetate; if monazite is present, minute ovals of sodium cerium acetate will appear.

Before the blow pipe, the mineral usually turns gray, but is infusible. If heated with sulfuric acid and transferred to the flame on a platinum wire, the phosphorus present colors the flame bluish green.7/

Monazite sand may be quickly and accurately identified by determining its optical properties with a petrographic microscope. Its high indexes of refraction, small axial angle, and strong birefringence are its distinguishing features.

MODE OF OCCURRENCE

Monazite sand is derived from the weathering of granites, gneisses and pegmatites in which it occurs as a primary mineral. The amount of monazite in the host rock seldom exceeds 0.1 percent, although crystals weighing as

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5/ Hess, Frank, Industrial Minerals and Rocks: Am. Inst. Min. and Met. Engr., 1937, p. 525.

6/ Kithil, Karl L., Monazite, Thorium, and Mesothorium: Bureau of Mines Tech. Paper 110, p. 10.

7/ Pratt, J. H., Work cited p. 10.

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much as 6 pounds have been found.8/ The commercial sands are obtained from beach and dune deposits. Inland placers along rivers and streams have been worked in the past. On the beaches the wave and tide action has reconcentrated the stream and river placer sands, and in the dune deposits selective wind action has concentrated the heavy sands into rich layers. The heavy sands commonly consist of ilmenite, zircon, rutile, and monazite in widely varying proportions. Quartz is the principal gangue mineral, and although the sands in some places contain garnet, hornblende, andalusite, and enstatite, efforts at separating and marketing of some of these minor constituents have proved unsuccessful.

Everywhere there is wide variance in the proportions and the minerals that constitute so-called monazite sands. The composite of heavy minerals obtained by rough gravity concentration of sands as found in nature is commonly called "crude sands."

In British India certain small areas contained up to 46 percent monazite but the commercial sands mined from 1906 to 1922 (before the ilmenite market was developed) averaged only 15 to 25 percent. Now, however, 2 to 5 percent monazite is contained in the sands mined principally for their ilmenite content. The Brazilian sands were rich enough originally to ship as found, but now they must be concentrated. In Malaya, monazite is associated with cassiterite; in Florida with ilmenite, rutile, and zircon; in the Carolinas with ilmenite, magnetite, rutile, garnet, hornblende, and gold; and in Idaho with gold, ilmenite, and zircon. In Ceylon, monazite constitutes only 8 percent of the heavy sands and the ilmenite 75 percent.

GEOGRAPHICAL DISTRIBUTION

World supplies of monazite have recently been obtained from British India, Netherlands Indies, and Brazil, and minor amounts from Ceylon, Australia, and Norway.

There has been no domestic production in recent years. North and South Carolina, Florida, and Idaho formerly produced monazite, but at present prices economic operations are not possible. In North Carolina the commercial sands were found mainly in Rutherford, McDowell, Burke, Cleveland, and Lincoln Counties; in South Carolina, in Spartanburg, Cherokee, Laurens, Greenville, Pickens, Anderson, and Occonnell Counties. Here, as in North Carolina, the deposits are scattered, and the gravel averages one-fourth to one percent monazite. The beach sands of Florida at Pablo Beach, south of Jacksonville, contain rutile, ilmenite, and zircon, but very little monazite.

8/ Schaller, Waldemar T., A Large Monazite Crystal from North Carolina: Am. Mineral., vol. 18, 1933, p. 435.

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The Idaho deposits are in the Centerville region, Boise County. Here the gravel contains gold, ilmenite, zircon, and from 0.1 to 0.15 percent monazite. Large crystals of monazite weighing as much as 60 pounds have been reported from pegmatites in Mitchell and Madison Counties, N. C.

In 1909, thoria-rich monazite sands were discovered in the State of Travencore in the extreme southwestern part of British India. Commercial sands have been found in four areas, but only two deposits are being exploited at present. Ilmenite and zircon in quite variable proportions occur on some beaches. Some of the sands contain an appreciable amount of enstatite; one sample of the nonmagnetic portion, which was 25.5 percent of the total sand, consisted of 40 percent quartz, 30 percent enstatite, and 30 percent zircon and rutile. Ordinarily, monazite is the most finely divided constituent.

In Brazil there are three types of deposits: (1) Beach deposits reserved by the Government; (2) beach deposits lying behind the Government reservation; and (3) inland deposits. Federal beach deposits extend inland 33 meters from mean high tide and have furnished most of the production. The States of Espirito Santo, Baia, and Rio de Janeiro have produced most of the Brazilian monazite.

Samples of sand containing 47 percent monazite with over 4 percent thoria have been obtained in the west coast of Ceylon. In Norway, monazite crystals are saved as a byproduct of feldspar mining, but the quantity never exceeds a ton a year.

Monazite is associated with cassiterite, fergusonite, euxenite, and gadolinite in Western Australia. Sands containing fergusonite are mined for their radioactive content near Copley in the southern part of Western Australia. In the New England region of New South Wales monazite is associaaed with tin and tungsten, and in the Malay peninsula the alluvial tin deposits contain varying amounts of monazite.

MINING AND SEPARATION

The crude, mixed, heavy sands are usually mined by simple, primitive methods using cheap, native labor. In British India natives use a hoe-like tool called a momati for gathering the monazite. The richer layers of heavy sands from the beach and dune deposits are either crudely concentrated on the beach or transported to near-by plants for separation. In former years the Brazilian sands were skimmed off the surface of the beach after each tide and shipped directly, but now they must be concentrated before being marketed. Attempts to mine monazite from the original host rock have

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proved unsuccessful, and byproduct production from feldspar and other pegmatite mining operations is negligible. Monazite should be considered as a potential byproduct from many placer-mining operations and should be looked for in the black-sand concentrates that accumulate in hydraulicking and dredging. Even in India and Brazil, monazite may be considered a byproduct of the mining of beach deposits for ilmentite, rutile, and zircon. Previous to 1922, mining in India was confined exclusively to the monazite-rich portions of the beach and dune deposits. Since then the extraordinary demand for ilmenite developed, and recovery of monazite became secondary. Formerly, simple gravity concentration was sufficient to reject the light quartz and produce a marketable monazite-rich concentrate, but now refined gravity concentration in combination with electromagnetic and electrostatic methods is used for recovery of both ilmenite and monazite.

Before 1907 Brazilian monazite was either shipped direct or was crudely concentrated in sluices yielding a 60- to 65-percent monazite associated with ilmenite, zircon, and quartz. However, after 1907 magnetic separators were used to make a monazite concentrate of 85 to 92 percent grade.

Gravity separation may be restricted to a rough concentration that rejects the lighter sands (quartz and feldspar) producing 20 to 30 percent monazite, or to a more refined gravity separation on shaking tables of the Wilfley type. The rough concentrates are dried and carefully sized (20, 50, 80, 100 mesh), and each fraction treated separately by electromagnetic separation, electrostatic concentration, or both. In electromagnetic separation with increasing magnetic intensity, the following products are separated: (1) Magnetite; (2) ilmenite and hematite; (3) garnet, platinum, epidote, apatite, olivine, and tourmaline; (4) monazite, with minor amounts of zircon, rutile, epidote, and other minerals; (5) fine grains of monazite; and (6) gold, zircon, rutile, quartz, feldspar, and other nonmagnetic minerals. A final separation of the nonmagnetic residue may be made on dry shaking tables, electrostatically or by a combination of these methods.9/

WORLD PRODUCTION

The locale from which the world supplies of monazite originate has shifted three times since 1894 and appears to be in process of changing again. The peak of world production, 7,392 short tons, was reached in 1909 and the low of 33 short tons in 1930; since then there has been an upswing, and in 1938 world production was 6,639 short tons.

9/ Taggart, A F. Handbook of Ore Dressing: John Wiley & Sons, 1927, p. 199.

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Records of production disclose that the United States supplied the world from 1886 until 1894. Peak production in the United States - 787 short tons - was attained in 1895. Subsequently Brazilian monazite appeared on the market in large quantities, bringing the American industry to a virtual standstill for the next few years.

Domestic production increased until 1905, when 672 tons were mined; thereafter it declined rapidly until 1911, when domestic mining ceased temporarily. Brazil, which attained an all-time peak production of 7,121 short tons in 1909, dominated the world market from 1895 to 1914 and has supplied more than 60 percent of the total monazite mined throughout the world. However, Brazil produced less monazite from 1914 to date than in the single year 1909. India's advance to dominance, due to availability of cheap labor and the high thoria content of the sands, has been rapid, and competition from other sources has virtually ceased. During World War I there was a resumption of domestic production and a slight increase in Brazilian output; since then there has been but 1 ton of domestic production, and the small Brazilian output has been maintained mainly to retain control of concessions. The Indian peak output of 5,850 short tons in 1938 was about 88 percent of the world total for that year; nevertheless, factors favoring the return of Brazil to a dominant position, at least for the duration of the war, are shorter sea lanes, higher rare-earth oxide content of sands, good-neighbor policy, and temporary menace of the Japanese in the Pacific. Ceylon, Netherlands East Indies, and Western Australia have contributed small supplies since 1936.

TABLE 5.- World production of monazite sand, 1893-1938, short tons

	United States	Brazil	India	Ceylon	Netherlands Indies	Total
1893	65	-	-	-	-	65
1894	273	-	-	-	-	273
1895	787	3,307	-	-	-	4,094
1896	15	192	-	-	-	207
1897	22	249	-	-	-	271
1898	125	2,149	-	-	-	2,274
1899	175	2,932	-	-	-	3,107
1900	454	1,633	-	-	-	2,087
1901	374	1,811	-	-	-	2,185
1902	401	1,328	-	-	-	1,729
1903	431	3,636	-	-	-	4,067
1904	372	5,357	-	-	-	5,729
1905	672	4,891	-	-	-	5,563
1906	423	4,797	-	-	-	5,220
1907	274	4,891	-	-	-	5,165

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TABLE 5. - World production of monazite sand, 1893-1938, short tons (Cont'd)

	United States	Brazil	India	Ceylon	Netherlands Indies	Total
1908	211	5,473	-	-	-	5,684
1909	271	7,121	-	-	-	7,392
1910	50	5,994	-	-	-	6,043
1911	-	4,064	932	-	-	4,996
1912	-	3,746	1,271	-	-	5,018
1913	-	1,584	1,383	-	-	2,967
1914	-	661	1,328	-	-	1,989
1915	18	484	1,241	-	-	1,743
1916	19	-	1,443	-	-	1,467
1917	11	1,252	2,173	-	-	3,436
1918	-	551	2,371	22	-	2,944
1919	-	161	2,267	-	-	2,428
1920	-	1,270	1,838	81	-	3,189
1921	-	366	1,411	84	-	1,861
1922	-	127	140	112	-	379
1923	-	-	276	-	-	276
1924	-	-	697	28	-	725
1925	1	22	.05	173	-	198
1926	-	221	72	-	-	293
1927	-	224	314	155	-	693
1928	-	112	116	112	-	340
1929	-	99	202	85	-	386
1930	-	17	16	-	-	33
1931	-	-	100	-	-	100
1932	-	330	733	-	-	1,063
1933	-	450	155	-	-	605
1934	-	-	1,128	-	-	1,128
1935	-	-	4,278	-	-	4,278
1936	-	-	2,942	-	736	3,678
1937	-	467	3,450	-	408	4,325
1938	-	356	5,850	-	433	6,639

NOTE. - Figures from various official sources. Data for years subsequent to 1938 are not available.

IMPORTS

Imports of monazite achieved an all-time high of 2,965 short tons in 1940, compared with the previous record of 2,914 short tons in 1917. Though considerable quantities have been stock-piled for future use, a definite increase in current consumption is indicated. Since 1910 the United States

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has had to depend upon foreign sources for its supply of crude monazite. Although Germany controlled the main supply of monazite until World War I, and the United States and England fostered infant industries during that war period, it was not until 1930 that we ceased to import thoria and rare-earth compounds, and not until 1934 that the German monopoly was broken.

Both the Governments of Travancore and Brazil collect a substantial royalty on the export of monazite. India has supplied the imports in recent years, but there is renewed interest in the Brazilian supplies.

TARIFF HISTORY

The following table shows tariff classification for monazite sand, thorium, and cerium:

Act of -	Paragraph	Tariff classification	Rate of duty - specific and ad valorem
1890	530	Cerium	Free
1894	432	do.	Do.
1897	183	Monazite sand and thorite	6 cents per pound
1897	518	Cerium	Free
1909	183	Monazite sand and thorite	4 cents per pound
1909	530	Cerium, cerite, or cerium ore	Free
1913	154	Monazite sand, thorite, and salts	25 percent ad valorem
1913	445	Cerium, cerite, and cerium ore	Free
1922	302	Cerium metal	$2 per pound
		Ferrocerium and all other cerium alloys	Do. 25 percent ad valorem
1922	1544	Cerite or cerium ore	Free
1922	1621	Monazite sand and other thorium ores	Do.
1930	1721	do.	Do.
1930	1644	Cerite or cerium ore	Do.
1930	302 (p)	Cerium metal	$2 per pound
1930	302 (p)	Ferrocerium and all other cerium alloys	Do. 25 percent ad valorem

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TABLE 6. - Domestic production and imports of monazite, 1895-1941

	Production			Imports		
	Short tons	Value	Unit value	Short tons	Value[1/]	Unit value
1895	787	$137,150	$174	-	-	-
1896	15	1,500	100	-	-	-
1897	22	1,980	90	-	-	-
1898	125	13,542	108	-	-	-
1899	175	20,000	114	-	-	-
1900	454	48,805	108	-	-	-
1901	374	59,262	158	-	-	-
1902	401	64,160	160	-	-	-
1903	431	64,630	150	-	-	-
1904	372	84,838	228	-	-	-
1905	672	162,308	241	-	-	-
1906	423	152,312	360	-	-	-
1907	274	65,754	240	-	-	-
1908	211	50,718	240	-	-	-
1909	271	65,032	240	35	$8,324	$238
1910	50	12,006	240	227	39,699	175
1911	-	-	-	353	60,542	171
1912	-	-	-	278	47,334	170
1913	-	-	-	409	65,848	161
1914	-	-	-	385	61,595	160
1915	18	3,600	200	937	161,456	172
1916	19	3,400	179	1,218	188,383	155
1917	11	1,760	160	2,914	355,017	122
1918	-	-	-	1,497	204,661	137
1919	(2/)	-	-	316	48,768	154
1920	-	-	-	907	141,528	156
1921	-	-	-	-	-	-
1922	-	-	-	1,733	210,187	121
1923	-	-	-	127	11,334	89
1924	-	-	-	273	18,320	67
1925	1	120	120	-	-	-
1926	-	-	-	335	23,816	71
1927	-	-	-	597	41,029	69
1928	-	-	-	442	24,151	55
1929	-	-	-	577	26,114	45
1930	-	-	-	-	-	-

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TABLE 6. - Domestic production and imports of monazite, 1895-1941 (Cont'd)

	Production			Imports		
	Short tons	Value	Unit value	Short tons	Value 1/	Unit value
1931	-	-	-	1,698	$65,080	$38
1932	-	-	-	1,569	48,639	31
1933	-	-	-	56	1,935	35
1934	-	-	-	112	4,867	43
1935	-	-	-	1,299	51,495	40
1936	-	-	-	607	25,324	42
1937	-	-	-	336	13,579	40
1938	-	-	-	456	18,210	40
1939	-	-	-	1,560	52,016	33
1940	-	-	-	2,965	99,827	34
1941	-	-	-	3/1,367	50,678	37

1/ At port of embarkation.
2/ One producer (no figures available).
3/ To August 1941.

MARKETING AND PRICES

The requirements of industry are rather limited and sporadic; therefore, specifications of buyers are elastic. Until 1933 the value of monazite was based upon the thoria content. The minimum requirement was 6 percent thoria until 1920, when it was raised to 8 percent. Since 1933 the basis for valuing monazite sands has been the rare-earth oxide content, although the trade journals continue to quote on the basis of 8 percent thoria. Occasionally buyers specify a 70-percent minimum rare-earth oxide plus thoria content for Indian sands and a 65-percent minimum for Brazilian, but generally they specify a 57-percent minimum rare-earth oxide content for Indian and 60-percent minimum for Brazilian.

Trade-journal quotations are nominal and do not indicate that a bona fide demand exists at the quoted price. The only means available for determining the value of monazite sand is by direct negotiation with the buyer. Some manufacturers show a preference for Indian sands because they are finer-grained and contain more thoria than the Brazilian. The United States and Germany have been the principal markets for monazite sand, and they are the largest producers of the rare-earth compounds and metals.

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TABLE 7. - Quoted monazite prices per short ton from Engineering and Mining Journal Metal and Mineral Markets, 1920-41

Year	Low	High	Year	Low	High	Year	Low	High
1920	$180	$252	1928	$120	$130	1936	$60	$75
1921	180	180	1929	60	130	1937	60	75
1922	120	180	1930	60	60	1938	60	75
1923	120	160	1931	60	60	1939	60	75
1924	120	160	1932	60	63	1940	60	65
1925	120	160	1933	50	63	1941	60	60
1926	120	120	1934	50	60	1942	60	60
1927	120	120	1935	60	60			

USES

Commercial utilization of the various elements in monazite sand began in 1885 with the development of the incandescent gas mantle. As thoria was the principal ingredient sought, large quantities of byproduct rare-earth oxides accumulated, for only a small amount of this residue was used in the manufacture of pyrophoric alloys.10/ As with many another byproduct commodity, many claims were made by researchers interested in developing new markets. Considerable technical skill and many chemicals are required to extract the rare-earth metals from monazite sands. Previous to 1940, 50 percent of our monazite consumption was used in the manufacture of arc-light electrodes, 25 percent for pyrophoric alloys, and 25 percent for mildew proofing, ceramics, and miscellaneous uses. Cerium is the most important rare-earth element used, and praseodymium, neodymium, and lanthanum follow in order of importance. At present cerium and the cerium group are used principally as arc stabilizers in carbon arc lamps, as a mildew-proofing agent, in alloys, and in the manufacture of pyrophoric alloys. Thorium is used principally in electron emissive elements, praseodymium and neodymium in the manufacture of special optical glasses, and lanthanum and erbium in beauty preparations. Other rare earths have little-known or no commercial use. For many purposes the rare earths are used as a group and are not separated into individual elements.

Metals and Alloys

About 25 percent of the monazite sand consumed in the United States is used in the manufacture of pyrophoric alloys for sparking flints in cigar and cigarette lighters. These lighters are used most widely in damp climates where matches are unserviceable. Small amounts are used in metallurgy as a refining and cleansing agent or are added to aluminum or magnesium to form high-strength lightweight alloys with good casting properties.

10/ Alloys of misch metal with iron or aluminum are pyrophoric alloys or material that, when filed, will produce a spark of sufficient heat to ignite vapors of light gases.

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The rare-earth oxide residue that remains after the extraction of thoria is known as misch metal when converted to the metallic state. Analyses of misch metal show the following range of composition: Cerium, 40 to 50 percent; lanthanum, 20 to 40 percent; yttrium, 1 percent; and small amounts of neodymium, samarium, gadolinium, and others, including some iron. Alloys of misch metal with iron or aluminum are pyrophoric alloys. The two best-known pyrophoric alloys are Auer metal and Kunheim. An analysis of Auer metal shows the following percentage composition: Iron 35, cerium 35, lanthanum 24, ytterbium 3, and erbium and others 2, whereas Kunheim contains aluminum 2, magnesium 12, and hydrogen combined as the metallic hydride 2; the remainder of both alloys is misch metal. Ferrocerium is another pyrophoric alloy containing approximately 33 percent cerium, 35 percent iron, 1.0 percent calcium, 0.4 percent copper, and 0.2 percent magnesium.

In the field of metallurgy, ferrocerium has been suggested as a refining agent. Cerium metal added to cast iron is said to aid in the removal of impurities (especially oxygen, nitrogen, and sulfur); increases the fluidity of the molten iron; and increases the hardness of the finished product.

Ceralumin C, a new aluminum alloy of low specific gravity and high strength, combined with good casting properties, was introduced in England in 1934. Analysis shows copper 2.5, nickel 1.5, magnesium 0.8, iron 1.2, silicon 1.2, cerium 0.15, and aluminum 92.65 percent. Investigators claim that the "cerium has a refining action on the microstructure, and it permits full utilization of the beneficial mechanical effects of a high iron content by suppressing the enbrittling iron aluminum combination."11/ This alloy is being used to a considerable degree in England in automobile and aeronautical castings.

Magnesium and its alloys are hardened by addition of 20 percent cerium or 6 percent cerium and 20 percent aluminum. Not more than 32 percent cerium or cerium-group metals are added in present practice. Such alloys are suitable for making pistons for internal-combustion engines.

Cerium Chemicals

Cerium compounds are commercially important. Textiles and canvases impregnated with cerium acetate are mildew-, moth-, and water-proof. The electrodes of arc lamps and searchlights contain cerium fluoride mixed with carbon to increase luminosity. The fluoride is also used to process cloth to

11/ Chemical Industries, New light alloy: Vol. 35, No. 4, October 1934, p.323.

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protect it against acids and corrosive vapors in filter presses and baghouses. Cerium nitrate is utilized in the manufacture of gas mantles, in tanning leather, and in dyeing and printing textiles.

Cerium oxide is used in ceramics and in the glass industry. The glass industry is said to be the largest user of cerium compounds, which are used in the production of special colors, signal glasses, and ophthalmic and scientific lenses with special optical and physical properties. An analysis of a special glass is 5 to 10 percent CeO_2, 50 to 60 percent SiO_2, 0 to 12 percen CuO, 0.1 to 0.5 percent CoO, and 12 to 25 percent Na_2O. It has been proposed as an opacifier, and it is said to improve the luster of enamels, but its high cost discourages commercial application. A pure oxide of cerium (opaline) has been developed for the production of gray nickel or cobalt-ground enamels for sheet metals. It has remarkable opacity and is not affected by furnace atmosphere. The oxides of cerium or cerium groups are used in nail polishes.

Ceric sulfate, $Ce(SO_4)_2$, recently developed in analytical chemistry, is widely applicable as an oxidizing agent. Cerium sulfate, $Ce_2(SO_4)_3$, is employed as a catalyst in making sulfuric acid and about 50 various organic compounds and is used in photography and in dyeing and printing in the textile industry. Cerium tungstate is an ingredient of a catalyst for making numerous organic compounds. In the electrical illuminating industry it is used in the treatment of carbons to improve their capacity to give more brilliant light.

In medicine cerium salts are said to have a tonic and antiseptic action.

Thorium Products

One of the most important uses of thorium is in the manufacture of radio tubes because of its electron emissive power, which enables the radio tubes to function.

Metallic thorium and thorium compounds are used in tungsten-lamp filaments, gas mantles, high-temperature refractories, radio-tube filaments, X-ray targets, and as a catalyst.

One percent thoria in tungsten-lamp filaments increases luminosity and renders the filaments less brittle. In the manufacture of gas mantles, a mixture of 99 percent thorium dioxide and 1 percent ceria give the best illuminating properties to the mantle.

In industrial chemistry thoria is used as a catalyst in oxidizing ammonia to nitric acid, carbon monoxide to water gas, and sulfur dioxide to sulfur trioxide, and in making many organic reagents.[12/] A patented alloy containing 0.005 to 10 percent thorium is said to be suitable for electrodes on

12/ Gregory, Thomas C., Uses and Application of Chemicals and Related Materials: Reinhold Publishing Corporation, New York, 1939, p. 602.

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neon lights. Thorium carbide mixed with iron carbide to produce a rich ultraviolet radiation may be used for making electrodes for sun and health lamps.

An alloy of tungsten, molybdenum, and thorium (the thorium content exceeding 1 percent) is a ductile, workable alloy capable of being drawn into extremely fine wires required in electronic discharge elements.

Thorium salts, which are all radioactive, possess little toxicity. Their astringent and tonic properties are said to be curative for certain parasitic skin infections. Insoluble thorium salts are used in creams and lotions. Thorium oxide forms a base powder insoluble in water or dilute acid and is used in dental powders and pastes.

Miscellaneous Rare Earths

Lanthanum salts have a bactericidal action and are utilized in beauty preparations, and erbium salts are astringents and find use in the same field.

The praseodymium and neodymium mixture, known to the trade as didymium, is used in the manufacture of special optical glasses, in the coloring of glass, as a bactericide, and as a component of an organic dye for marking gas mantles. Glasses containing didymium absorb two bands in the spectrum, and this property finds application in the manufacture of special lenses to protect the eyes of workers from harmful rays. Other lenses of didymium are said to correct incomplete color blindness. In the manufacture of special colored glasses combinations of neodymium and praseodymium give all the shades from neutral gray to light ruby, grayish blue, or brown green.

IMPORTERS AND CONSUMERS OF MONAZITE SANDS

Importers:

Indian -

C. Tennant Sons & Co.
9 Rockefeller Plaza,
New York, N. Y.

Brazilian -

Rare Mineral & Metals Co.
40 Exchange Place,
New York, N. Y.

Maywood Chemical Works,
Maywood, N. J.

Foote Mineral Co.
16th & Summer Sts.,
Philadelphia, Pa.

Consumers:

Lindsay Light & Chemical Co.
West Chicago, Ill.

Maywood Chemical Works,
Maywood, N. J.

Woolf-Alport,
1127 Irving Ave.,
Brooklyn, N. Y.

National Carbon Co., Inc.,
Carbon Sales Division,
11701 Madison Ave.,
Cleveland, Ohio.

New Process Metal Corporation,
Newark, N. J.

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